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DORM: Narrowband IoT Development Platform and Indoor Deployment Coverage Analysis

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Abstract

The development of DORM (integrated cOmpact naRowband platforM) node is presented that combines low cost and low power components in a multi-layer architecture to support versatile NB-IoT applications. In our proposed DORM node, the processing component provides an interface to a variety of sensors and the radio component provides connectivity to the IoT cloud as required by IoT applications. Furthermore, an overview of our NB-IoT test network is presented that is deployed at Tallinn University of Technology (TalTech) campus, Estonia with a detailed description of its various functionality layers. In addition, an in-field investigation of the coverage of our NB-IoT system is made whereby our DORM nodes are deployed across the TalTech campus so as to explore its connectivity performance and possible issues in an indoor scenario. We made empirical measurements on NB-IoT coverage for different elevation levels, a key performance indicator that most of the operators would be interested in. We obtained averaged SNR and RSSI values in the range of 18 dB to 23 dB and -65 dBm to -70 dBm, respectively. Our obtained results show that our NB-IoT system provides an excellent connectivity in indoor environments and can satisfy IoT application requirements. However, small variations in these SNR and RSSI values are observed at different elevation levels possibly due to positioning of the measuring nodes, proximity of the antenna with respect to the base-station, building structure and its construction material and the surrounding environment of the placement of our DORM nodes.

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1. Introduction

LPWAN includes diverse competing technologies such as Sigfox, LoRa, LTE-M, NB-IoT, Ingenu, and Telensa, etc., [1-2], but NB-IoT outperforms all other LPWAN technologies in terms of coverage, energy efficiency, and cost by utilizing the existing cellular infrastructure [3]. NB-IoT is a variant of the long-term evolution (LTE) that uses 180 kHz bandwidth and corresponds to one physical resource block (PRB) of LTE. NB-IoT can be deployed in three different modes, i.e., in-band and guard-band within the existing LTE band, and standalone mode outside the LTE band. The choice of mode selection is critical and has an impact on the overall network coverage, quality of service (QoS) as well as capital expenditure (Capex). To support the flexibility and switching between these modes, NB-IoT extensively uses the LTE design such as OFDM in downlink and single carrier frequency-division multiple access (SC-FDMA) in the uplink. However, many design changes such as retransmission for coverage extensions, scheduling delay for reducing computational complexity, power boosting for downlink transmissions have been introduced to ensure its best coexistence with the existing LTE infrastructure and to fulfil the need of IoT applications. The detailed design changes with a key insight on the technology can be found in the standard in [4].

NB-IoT allows long-range communications at low data rates and is most suitable for delay-tolerant applications. It can provide a data rate of 250 Kbps for multi-tone downlink communication and 20 Kbps for single-tone uplink communications. For data collection at the lowest layer, NB-IoT utilizes end-nodes that are powered by chargeable batteries and are embedded with sensors for gathering data from their surroundings.

The device complexity of NB-IoT nodes is reduced as compared to other unlicensed LPWAN technologies including LTE-Cat M1 devices for addressing the ultralow-power IoT applications. The NB-IoT nodes feature battery saving modes such as PSM and eDRX to achieve higher energy efficiency and longer battery life where the future NB-IoT nodes are expected to have a battery life of more than 10 years as per the standard.

There are already existing NB-IoT deployments around the world, such as NB-IoT at sea in Norway [5], Connected Sheep in Norway [6], Smart metering and tracking in Brazil [7], Smart City in Las Vegas [8], and 346 NB-IoT covered cities in China [9]. These examples illustrate the fast growing interest in and adoption of NB-IoT for practical use-cases. However, the information available about the underlying platforms is focused on the use-cases and do not present details about the implementation at the device and network levels. Thus, so far, publicly available details on NB-IoT real-life performance are scarce.

As part of our ongoing research efforts on NB-IoT, our group has built and deployed a test platform comprising 50 NB-IoT (DORM) nodes, a commercial base-station from Telia Eesti, and a cloud backend server to gain and share an in-depth understanding of NB-IoT. The goal of this paper is two-fold. Firstly, to develop an integrated (DORM) platform using commercial-off-the-shelf (COTS) hardware components to enable seamless multi-interface connectivity that can provide end-to-end solutions for NB-IoT applications. Secondly, we present preliminary experimental results that characterize the real-life performance of NB-IoT in an indoor scenario for different elevation levels by utilizing Telia's commercial base-station that is installed at the premises of TalTech campus. In particular, our results show the impact of different elevation levels on the performance of NB-IoT in an indoor scenario and the corresponding penetration losses that are investigated in details.

The rest of this paper is organized as follows. In Section II, we present our NB-IoT system setup that is installed at TalTech campus and we discuss its various functionality layers in detail. Section III presents the results generated by the NB-IoT system setup at the TalTech campus in terms of its coverage and connectivity. Section IV concludes this work with some future directions.

2. NB-IoT System Architecture installed at Tallinn University of Technology (TalTech) campus, Estonia.

A generic IoT system is comprised of a number of blocks to facilitate functionalities such as sensing and monitoring of the surroundings, exchange and communication of data, management and analysis of information, investigation and decision making, and storage and backup of data for future use. In this work, we present the NB-IoT system setup that is deployed across TalTech campus and we discuss its various functionality layers as shown in Figure 1. The three layers of this NB-IoT system can be categorized as under:

1. Perception layer (DORM nodes are deployed across TalTech campus for sensing the surroundings.)
2. Network Layer (Telia's commercial Base-station is installed at TalTech campus that supports 5G network.)
3. Cloud Platform (Cumulocity server is setup for supporting and interfacing users' applications.)

DORM nodes are deployed across TalTech campus to collect data from their surroundings through dedicated sensors, packs the collected data into proper format, and transmit it to the next higher layer i-e., "Network Layer". At the "Network Layer", a commercial Base-station (BS) operated by Telia, supports LTE Cat-NB1 network to collect all the transmitted data from the deployed nodes and send it further to the highest layer of the NB-IoT system i-e., "Cloud Platform Server". The "Cloud Platform Server" provides an interface for secure communication between the NB-IoT Network and the users' applications, data analytics for decision making and data storage for backup and future use. In the subsections that follow, each of the layer of our NB-IoT system at TalTech campus is explained in details.

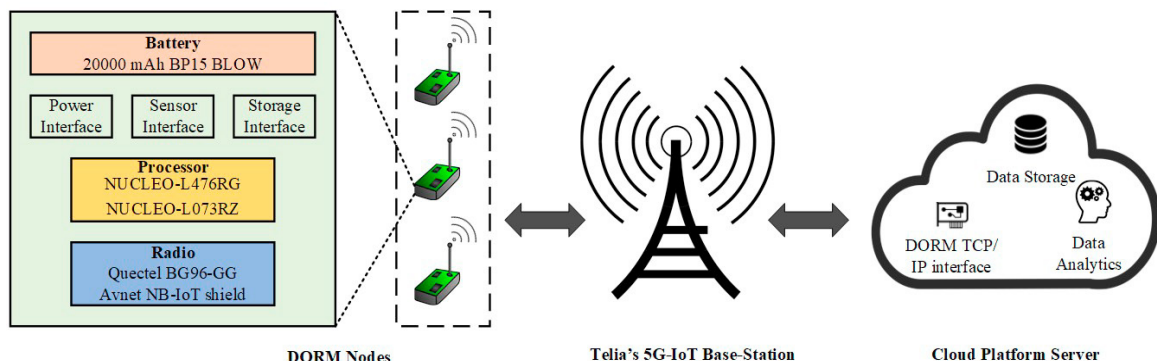


Figure 1: Architecture of NB-IoT setup at Tallinn University of Technology (TalTech) campus, Estonia.

2.1. Perception Layer (DORM nodes)

Many enabling technologies are used to setup customizable IoT nodes that can collect data from their surroundings and sends it to the cloud for further analysis and investigation. Most developers opt for microcontroller-based boards such as Arduino, Nucleo, etc., that can collect and process the data coming from the sensors and a radio module such as Texas Instruments, Quectel, etc. to provide an Internet connection to the network or cloud. However, the choice of microcontrollers (MCUs) and radio modules is often very complex, due to the fact that a trade-off between costs, performances and functionalities is needed for each particular application.

The two versions of our DORM nodes are shown in Figure 2. They combine ultra-low-power STM32-based Nucleo boards (L476RG (Cortex M4) [10] or L073RZ (Cortex M0+) [11]) with Quectel BG96 chipset-based boards (Avnet Silica NB-IoT shield [12] or Quectel GSM/NB-IoT EVB Kit [13]) and are powered by an external 20000 mAh BP15 BLOW battery. The STM32-based Nucleo boards are used as the processing units as they are highly affordable and can be extended with a large number of hardware add-ons to seamlessly work with a wide range of sensors. The Quectel BG96 radio chipset features ultra-low power consumption and supports LTE Cat NB1 (i.e. 3GPP Release 13 NB-IoT) along with a set of industry-standard interfaces (such as USB/UART/I2C/Status Indicator) suitable for a wide range of IoT applications.

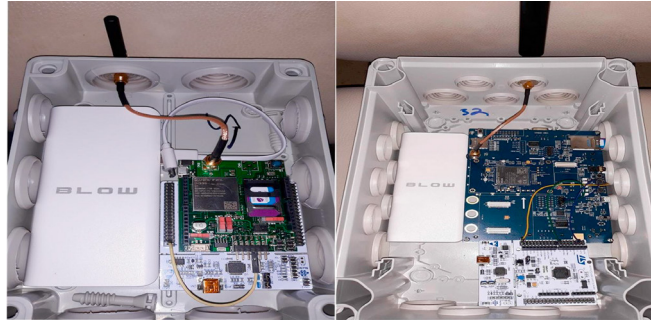


Figure 2: DORM nodes: Left: NUCLEO-L476RG board + Quectel BG96-GG Starter Kit. Right: NUCLEO-L073RZ board + Avnet Silica NB-IoT Sensor Shield (BG96).

Inside our DORM nodes, the data collected by sensors is transferred to the STM32 microcontroller through dedicated interfaces where it is encapsulated into UDP packets format and sent to the BG96 module through UART interface. The BG96 module first establishes a secure connection with the BS and afterwards sends the data to the NB-IoT network. Figure 3 shows a snapshot of the QCOM interface where the BG96 module establishes an LTE Cat NB1 connection with the BS through the use of AT commands before sending any data to the network.

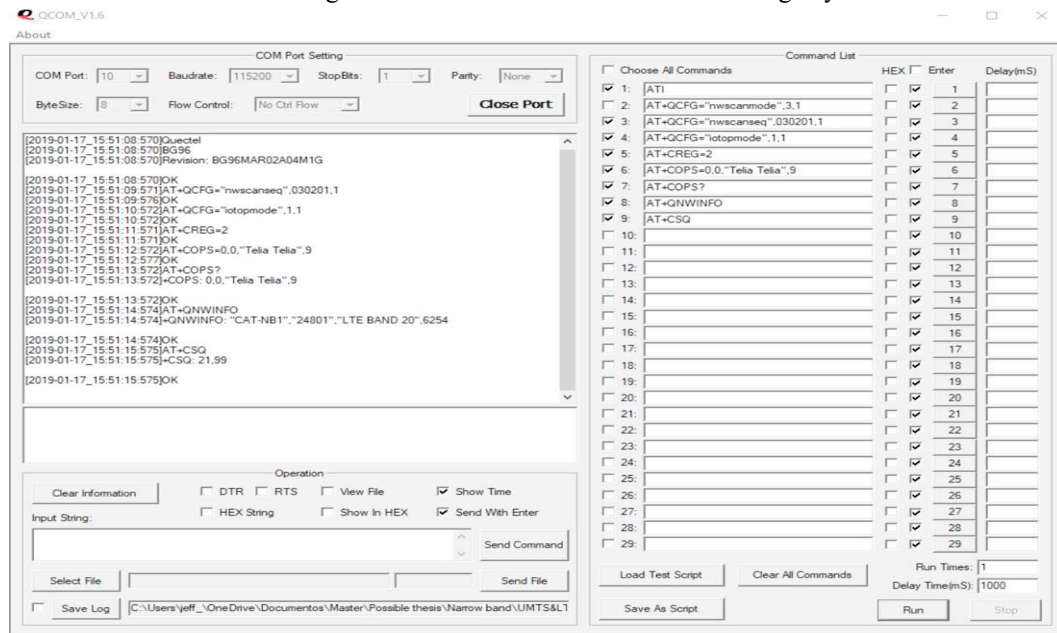


Figure 3: Set of AT commands used by BG96 module to establish connection with the BS.

The first (ATI) command delivers product information to the user which in our case is Quectel BG96 module. The second (AT+QCFG="nwscanmode") command specifies the RATs (Radio Access Technologies) to be searched where we have specified to look for LTE RAT only. The third command (AT+QCFG="nwscanseq") specifies the searching sequence of the available RATs where our search sequence is (e.g.: 030201) LTE Cat NB1, LTE Cat M1 and GSM. The next (AT+QCFG="iotopmode") command configures the Network Category to be searched under LTE RAT and we configure it for LTE Cat NB1. Afterwards, the (AT+CREG) command enables the network registration, and the AT+COPS command returns the currently selected network operator which in our case is Telia. Once registered with the network, the (AT+QWINFO) command indicates the network information such as the access technology selected, the operator, and the band selected. Finally, (AT+CSQ) command provides the signal quality in terms of received signal strength (RSSI) of the network. Further information on these and related AT commands can be found in [14].

2.2. Cloud Layer (Cumulocity Application)

In a typical IoT system, the cloud analyse all the data traffic that comes from the IoT nodes through the gateway network to give an accurate feedback to the user (application). Predictive analytics in data mining could be used for analysing and predicting the possible outcomes. The cloud services must also guarantee the security and QoS capabilities where the data must be stored in a safe and secure storage for future needs. Our cloud platform in the NB-IoT setup at TalTech campus features a secure communication between the NB-IoT Network and the Cumulocity backend server that provides a user interface for IoT applications. The data that is received from any particular DORM node is securely stored on the Cumulocity backend; where a trace of all the previous data with device ID, location and timings is kept securely. A snapshot of the Cumulocity online dashboard for the SNR and RSSI values received from DORM node 15 (iot_tester 15) at particular date and time is shown in Figure 4.

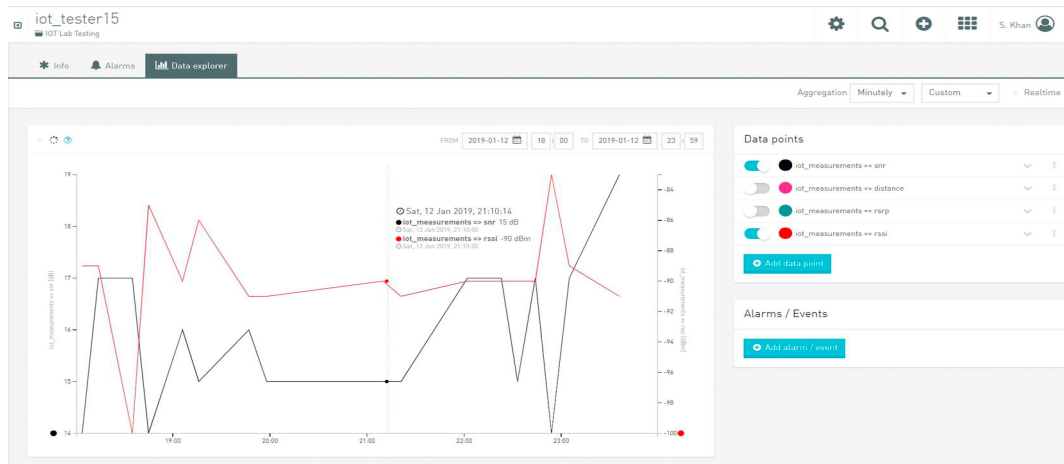


Figure 4: The SNR and RSSI values received at the Cumulocity server from IoT Tester 15 on Sat, 12 Jan 2019 from 18:00-23:59 respectively.

3. Results generated by our NB-IoT System at Tallinn University of Technology (TalTech) campus, Estonia.

With an aim to investigate the indoor coverage of our NB-IoT system at TalTech campus, we choose an observation point inside our building, hosting Thomas Johann Seebeck Department that is at a distance of 300 m from the BS, as shown in Figure 5 (left). DORM nodes were deployed at different elevation levels (floors) of this five-story building at almost the same location where the height of these floors from ground are: 1st floor is 0 m, 2nd floor is 03 m, 3rd floor is at 09 m, 4th floor is at 12 m, and 5th floor is at 15 m, respectively. Furthermore, the Base-station is at a height of around 20 m from the ground as shown in Figure 5 (right).

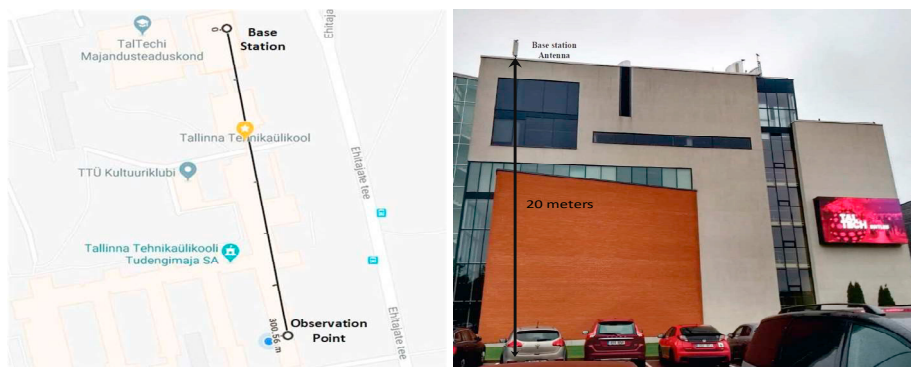


Figure 5: Our observation point is 300m away from the BS as shown by Google Maps (left) where our BS is 20m above the ground (right).

Table 1 presents the average results obtained from DORM nodes at different elevation levels (floors) for a duration of 6 hours in the morning (08:00-13:59) and a duration of 6 hours in the evening (18:00-23:59) at an observation point that is 300 m away from the BS. The columns for Signal Strength in Table 1 are derived and based on the RSSI scale values for NB-IoT presented in [15] and summarized in Table 2. The obtained SNR and RSSI values show that our installed NB-IoT system at TalTech campus provides good connectivity to satisfy the IoT application requirements in indoor environments for different elevation levels.

Table 1: Average SNR and RSSI values obtained at 300m from the Base-station for different elevation levels.

Floor Number (Elevation from the ground)	Observation point at 300 meters from the BS					
	Morning (08:00-13:59)			Evening (18:00-23:59)		
	Avg. SNR (dB)	Avg. RSSI (dBm)	Signal Strength	Avg. SNR (dB)	Avg. RSSI (dBm)	Signal Strength
5 th Floor (15 m)	18.11	-65.75	Good	19.13	-64.93	Good
4 th Floor (12 m)	18.68	-67.50	Good	19.74	-66.61	Good
3 rd Floor (9 m)	21.12	-68.04	Good	21.33	-67.71	Good
2 nd Floor (3 m)	21.28	-69.48	Good	21.75	-68.92	Good
1 st Floor (0 m)	23.58	-70.20	Good	23.74	-69.70	Good

Table 2: NB-IoT Signal Strength (RSSI) reference values [15].

LTE	NB-IoT	Signal Strength
> -65 dBm	> -60 dBm	Excellent
-65 to -75 dBm	-60 to -80 dBm	Good
-75 to -85 dBm	-80 to -95 dBm	Fair
-85 to -95 dBm	-95 to -110 dBm	Poor
< -95 dBm	< -110 dBm	Disconnect

As evident from the results as shown in Table 1, there is a clear difference between the averaged SNR and RSSI values obtained at different timings of the day. In the morning, the obtained SNR and RSSI values are lower than those obtained in the evening and the reason for this could be an increased human activity during the peak hours of the morning. Conversely, when human activity comes to a cease with the closing of the day (in evening), the obtained SNR and RSSI values are slightly higher. The same phenomena could be observed from the graphs obtained in Figure 6, where a lot of disturbance is seen during the peaks hours in the morning as visible from variations in the SNR and RSSI values. However, these variations smooth out when most of the human activity comes to a cease during the close of the day. Our results also show that there is a higher packet loss ratio at higher elevation levels (top floors) than those at lower elevation levels (down floors). These packet losses are indicated by broken lines of the graphs in Figure 6 where each discontinuity represents a packet loss.

In terms of elevation levels, the SNR and RSSI values are in the range of 18dB to 23dB and -65 dBm to -70 dBm, respectively. This shows that our NB-IoT system setup at TalTech campus provides an excellent coverage in an indoor scenario for all elevation levels. However, little variations in the signal strength are observed at different elevation levels due to the positioning of devices, proximity of antenna with respect to the base-station, building material and its structure and the surrounding environment of each particular location of placement of DORM nodes.

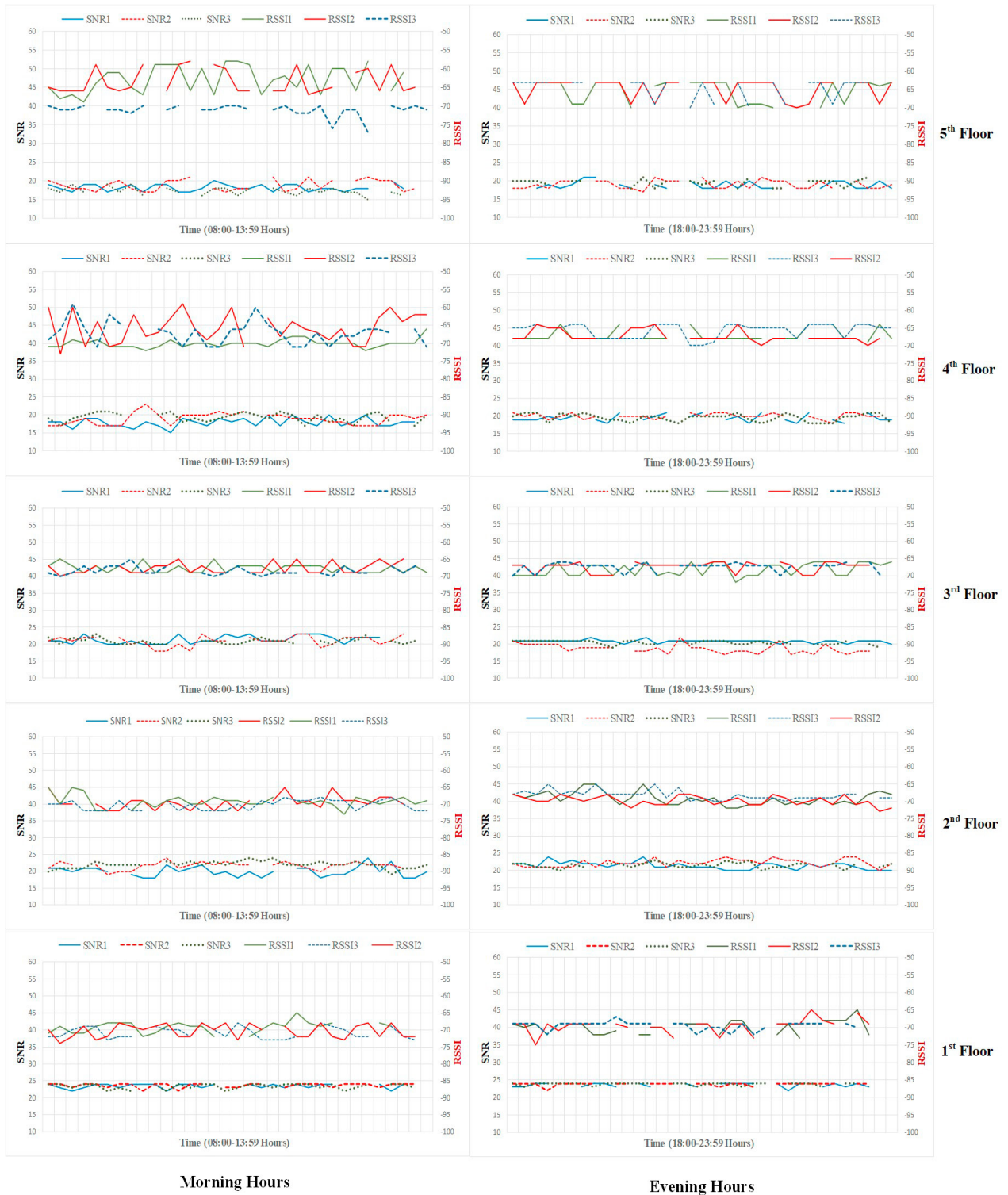


Figure 6: Data collected at different hours of the day for various elevation levels (Floors). The graphs in the left column portrays the SNR and RSSI values collected during morning hours (08:00-13:59) while the graphs in the right column shows the data collected in the evening hours (18:00-23:59).

4. Conclusion and Future Directions

The NB-IoT system architecture at Tallinn University of Technology is presented where DORM nodes are deployed across the TalTech campus to collect data from their surroundings within the coverage range of the installed NB-IoT Base-station. The development of our DORM nodes from the available COTS technologies is discussed where they are capable of collecting data from their surroundings through embedded sensors, encapsulating the collected data into a proper format and sending the formatted data to the IoT cloud for further analysis and investigation. Additionally, the NB-IoT system's coverage at TalTech campus is analysed in terms of the received SNR and RSSI values for different elevation levels and the produced results are discussed.

In future, we plan to extend this work with a comprehensive real-life investigation of the energy consumptions of our DORM nodes and further research towards Green IoT solutions.

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